Biomorphic Ceramics from Lignocellulosic Templates

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Outline

- Introduction
- Anisotropy in Biological Systems in Nature
  - *Plants, Animals, Humans, etc.*
- Wood as Engineering Material
  - *Anisotropic Properties*
- Results and Discussion
  - *Thermal Conversion of Cellulose Templates*
  - *SiC Based Ceramics from Cellulose Templates*
  - *Templates for Carbon Nanotube Growth*
  - *Biomaterials for Orthopedic Implants*
- Summary and Conclusions

Why Look to Nature ?

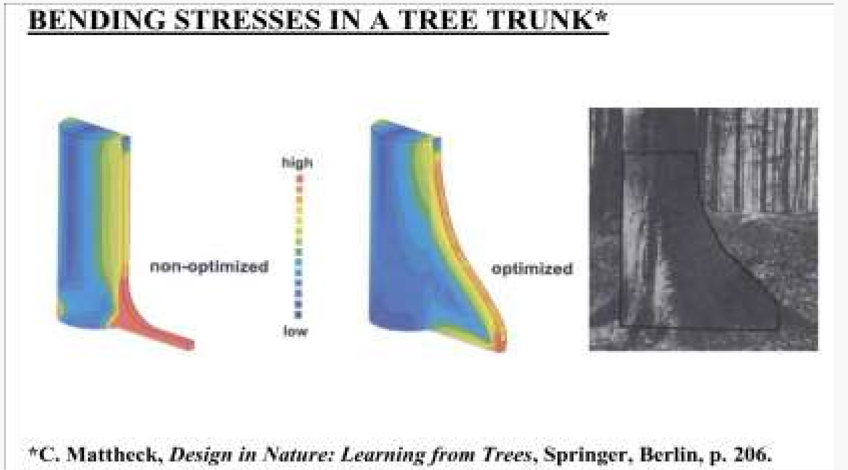
Termites build columns with heights that 2500 times their length

If Humans were to do a proportional thing, the structures would be 4600 meters tall (Prof. Turner's Book)

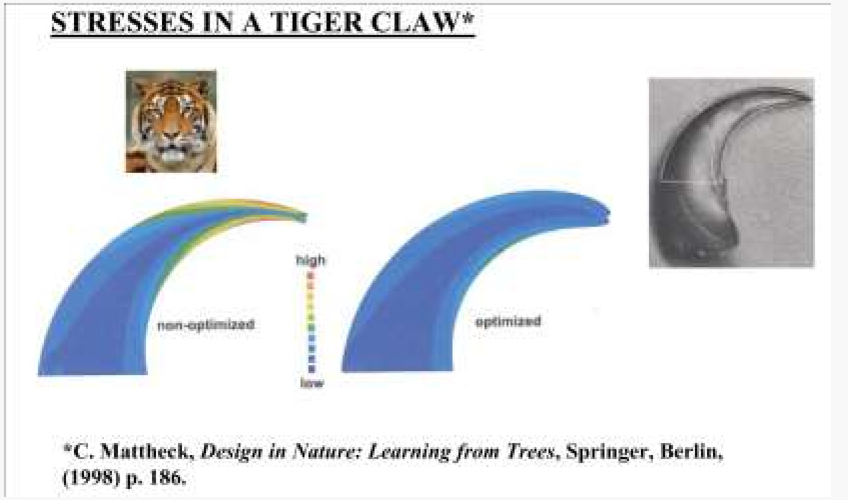
Natural Structures are Impressive

The Tallest Tree, a REDWOOD, is 111 meters High.

(EVAPORATIVE POSITIVE-DISPLACEMENT PUMP)



Biological Systems in Nature are Optimized



Nature Optimized Design Concepts for Commercial Products

Solar Biomimicry

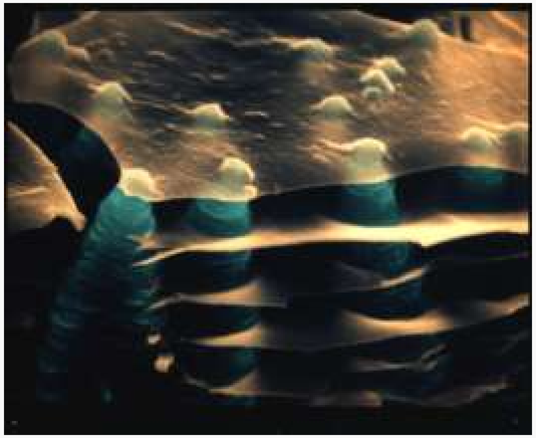
Whale Biomimicry

Whale Flipper (Wind Power)

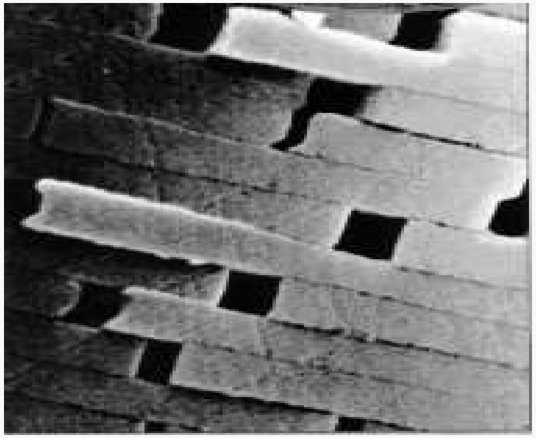
Tom Mueller, Biomimetics: Design by Nature, National Geographic, August 2008.

Strong, Lightweight Ceramics from Nature

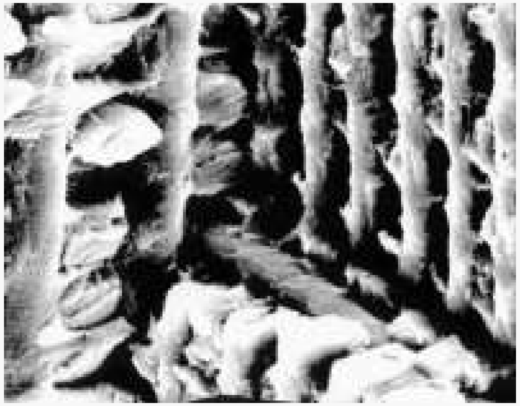
Abalone Shell



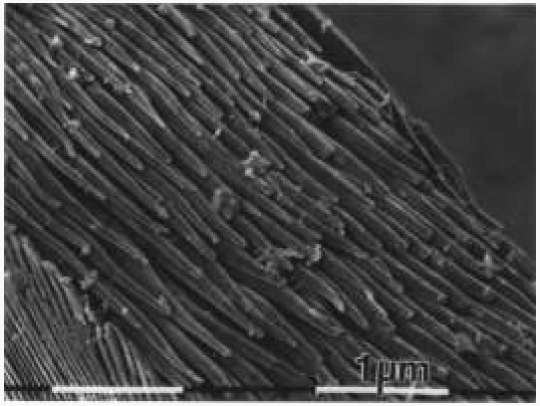
Growth Edge of Red Abalone



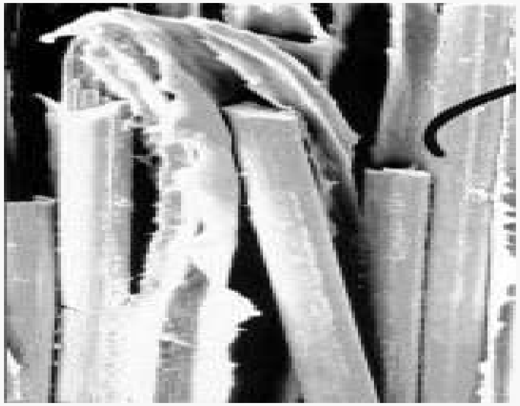
$CaCO_3$ Laminated (Layered) Structure Provides Toughness



Rat's Tooth (Hydoxyapatite in Collagen Matrix)



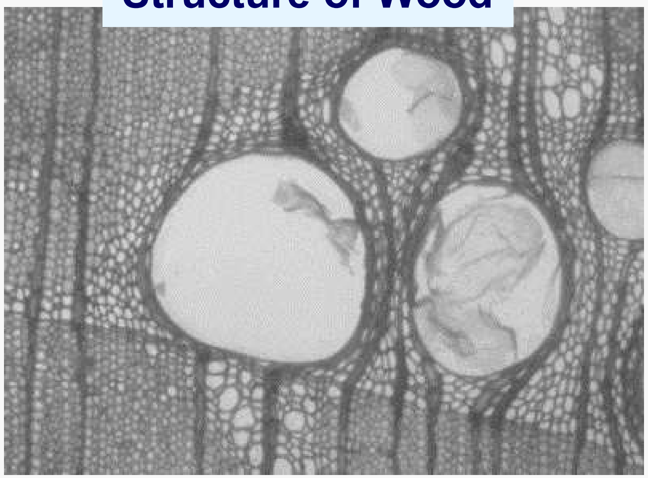
Sea-Urchin Teeth ($CaCO_3$ calcite-fibers in $CaCO_3$ matrix)

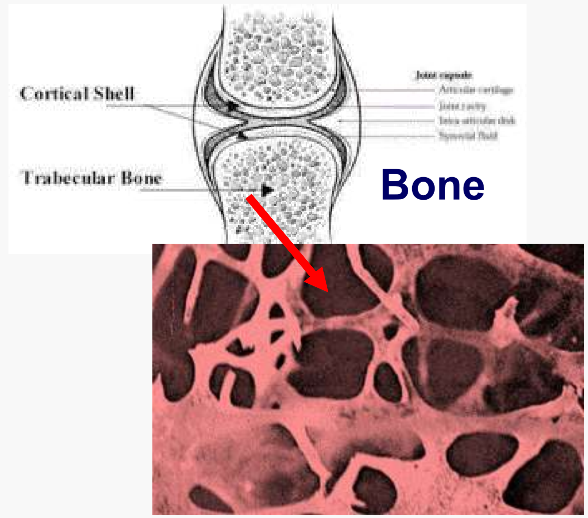


Shell of Bess Beetle (Fibrous Composite)

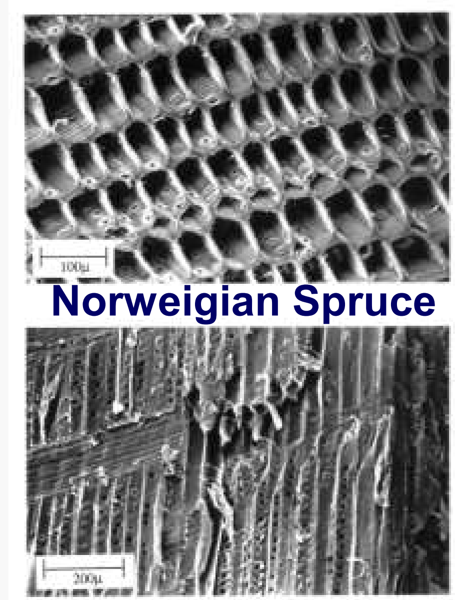
Many Biological Structures in Nature Are Porous With High Level of Ordering

Structure of Wood



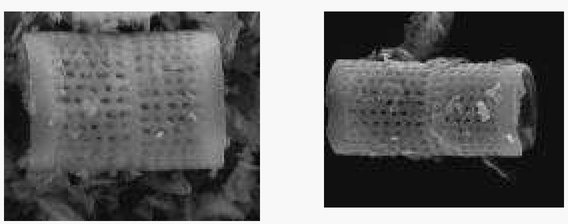


Bone



Norweigian Spruce

Structures Found in Nature Are Self-Assembled



Diatoms- self-assembled
Silica based microorganisms

Some Features of Biological Systems:

- Porous, with pore sizes ranging from nanometers to microns
- Varying degree of ordering of the structure in three dimensions
- Self assembled
- Adaptive to different load situations
- Combination of structural and functional characteristics

Wooden Girder Bridges in Amsterdam

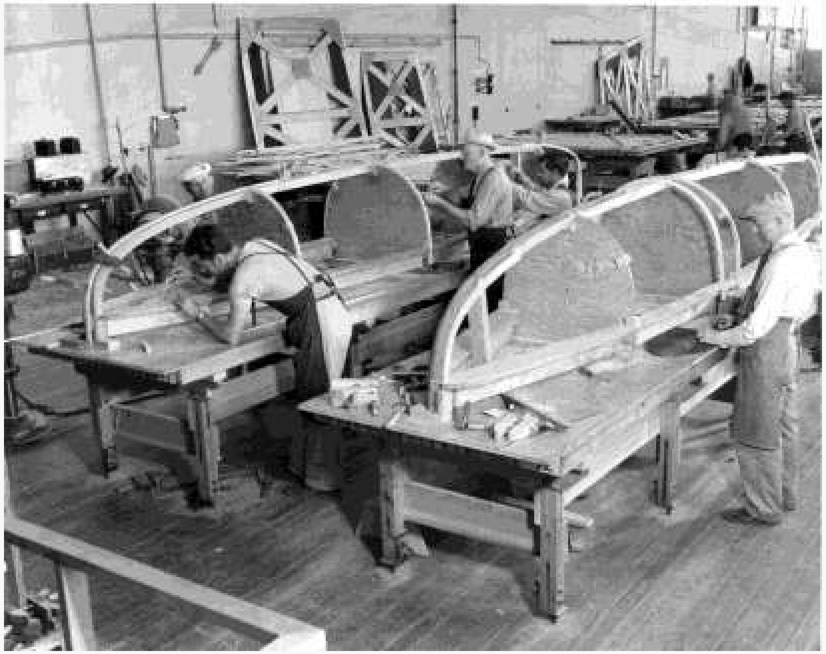
Bridge 102
(1795)

Todaiji Temple, NARA, Japan

(Largest Wooden Structure in the World)

Howard Hughes Flying Boat "Spruce Goose"

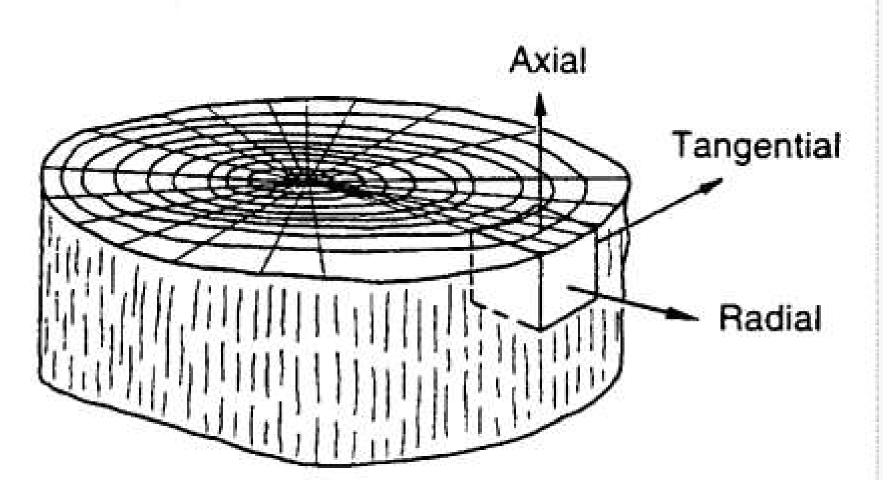
(Biggest Aircraft Ever Built)

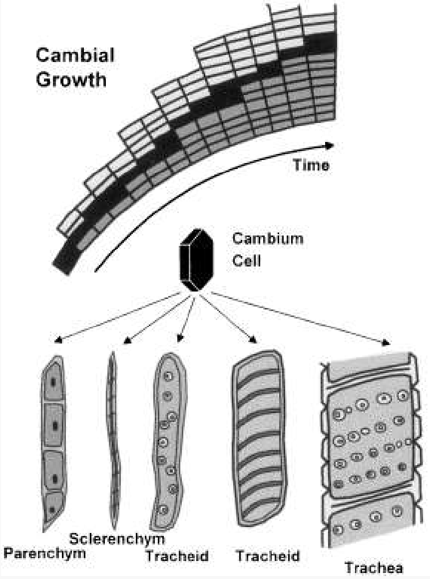


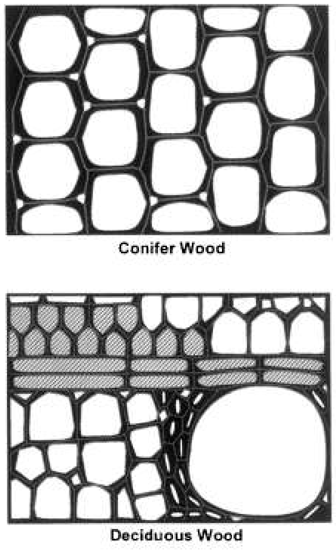
- ***Wingspan: 319.92'; Fuselage: 219'; Tailspan: 113.5'; Vertical Tailspan: 49.5'***
- ***Gross Weight: ~ 400,000 pounds; Fuselage Height: ~ 30'***
- ***Cruising Speed: ~ 200 mph***

Microstructure and Anatomy of Wood

- **Wood is a hierarchical cellular solid with relative density between 0.05 – 0.80.**
- **Composed of highly elongated cells (10-1000 aspect ratio) that make the bulk of the wood, rays (made up of smaller more rectangular cells) and sap channels.**
- ***Softwoods:* Cells relatively thin walled and interconnected by openings which allow fluid transfer. Rays are narrower and extend few cells in the axial direction.**
- ***Hardwoods:* Cells shorter, thicker walled, and provide strength. They also contain sap channels of much larger diameter. Rays extend hundreds of cells in the axial direction.**

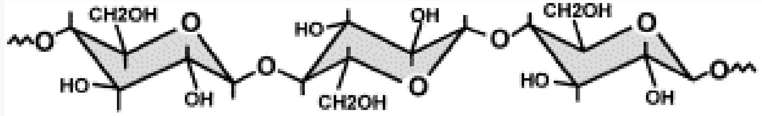




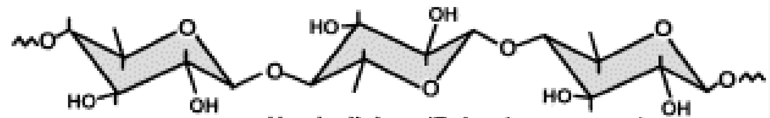


Anatomy and Composition of Wood

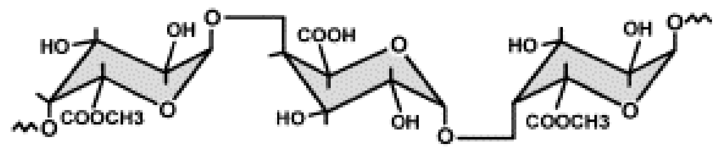
- Cell walls are made of fiber phase of crystalline cellulose in a matrix of amorphous hemicellulose and lignin ⇒ *fiber reinforced composite*.
- The lay-up of fibers in the wall is complex and critical for the strength and anisotropy. The cell walls are helically wound with the fiber direction nearer to the cell axis.
- The cell aspect ratio is another critical factor.



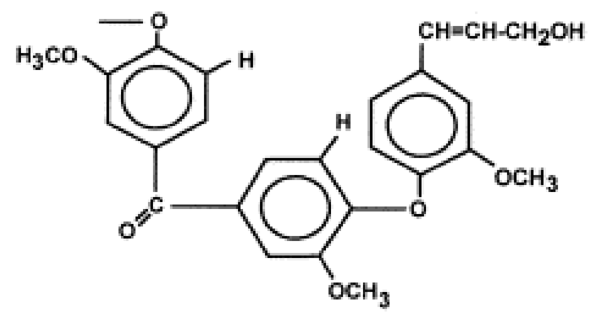
Cellulose (Polyglucosan)



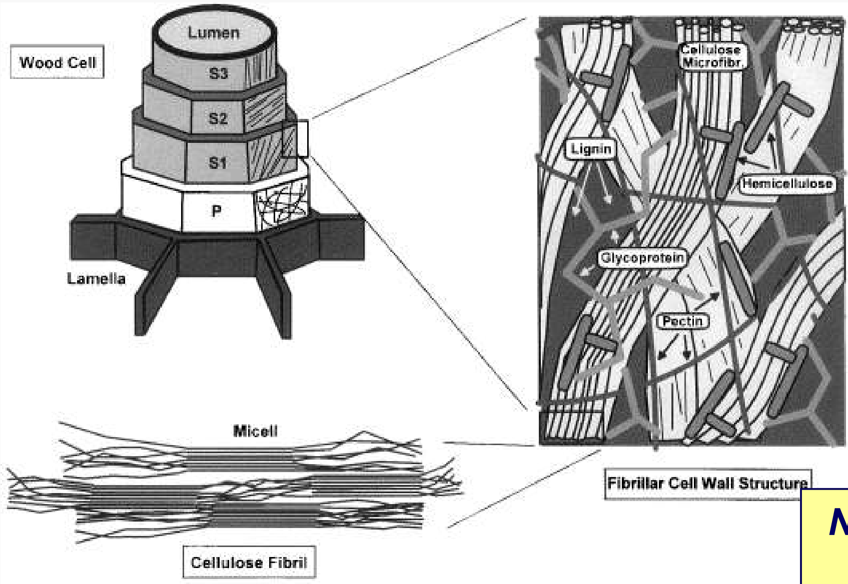
Hemicellulose (Polyxylopyranosan)



Pectin (Polygalacturonan)



Lignin (Phenylpropanol)



Natural tissues exhibit hierarchy, selectivity, and anisotropy combined in the cellular anatomy

Ecoceramics Technology

2001 R&D 100 Award, 2002 NorTech Innovation Award

Natural Wood
(formed into net shape)

Wood Saw Dust
(mixed with binder
and made in to net shapes)

Pyrolysis
(up to 1000 °C)

Bio-Oil

Silicon Infiltration

Oxide Infiltration

SiC-Based Ceramics
(Porous & Dense)

Oxide Coated Carbon System

SiC/Oxide Ceramics

Bio-Oil (Pyrolysis Liquid) Can be Used as Renewable Energy Source

Properties of Wood Derived Bio-Oil

- **Moisture content : 15-30%**
- **pH: 2.5**
- **Specific gravity: 1.2** ***(0.85 fuel oil)***
- **HHV as produced: 16-19 MJ/kg**
  (Half of the conventional fuel oil)
- **Viscosity: 40-100 cp**
- **Solids (char): 0.5%**
- **Elemental analysis: C (56.4%), H (6.2 %), O (37.3%), N (0.1%), Ash (0.1%)**

Professor Tony Bridgwater
Aston University, UK

Plant to Make BioOil From Wood and Other Types of Biomass

DynaMotive Technologies Corp. and Orenda Turbines, Canada

2.5 MW GT 2500 Turbine Generator

Advantages of Low Cost and Renewable Cellulosic Precursors for Ecoceramics

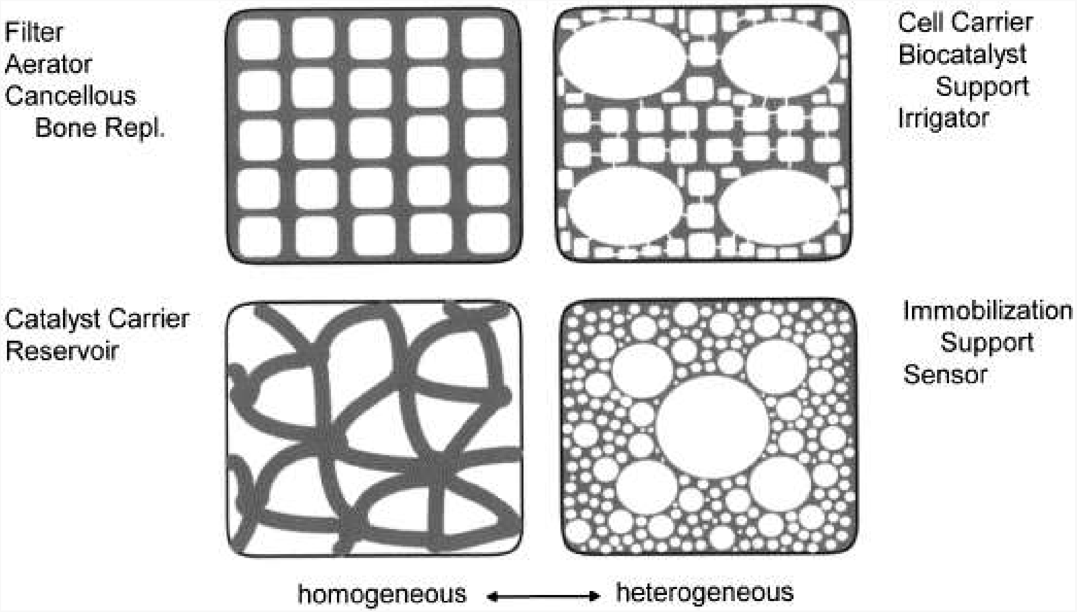
- ***Carbonization (Pyrolysis) of Natural Wood***
  - Wood and carbon preforms can be fabricated in to near-net and complex shapes
  - No toxic gases generated during carbonization
  - Low cost
  - Multifunctional materials (anisotropic, FGMs)
- ***Preforms From Saw Dust From Timber Mills***
  - Carbon preforms with saw dust as main component
  - Low cost, Isotropic materials

- ***Ecoceramics vs Traditional Ceramics***
  - Use of Renewable Starting Materials
  - Utilization of Industrial Wastes (Conservation of Natural Resources)
  - No Toxic Pollutants Generated During Manufacturing
  - Lower Manufacturing Cost

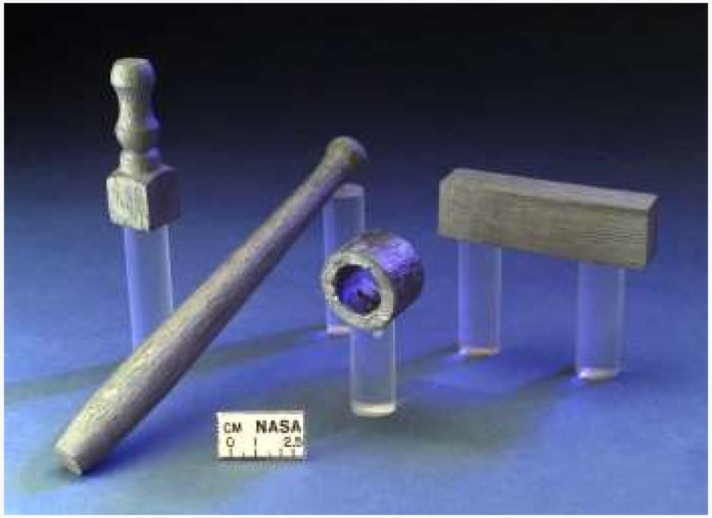
Environmentally Conscious Green Manufacturing

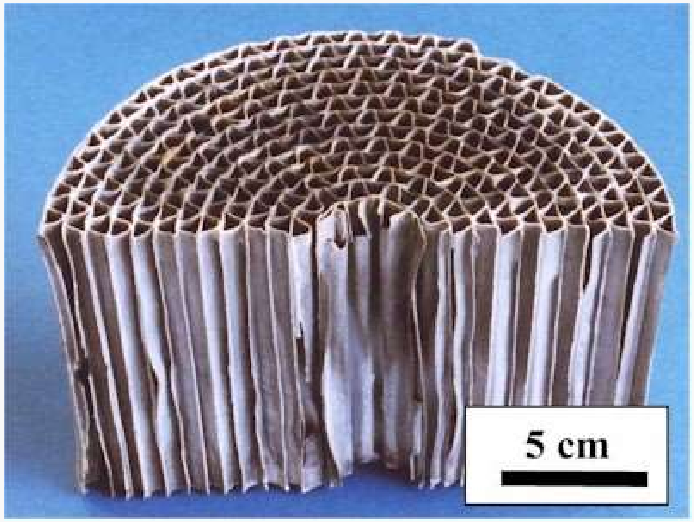
Potential Applications of Ecoceramics Materials and Components

- Filters and catalyst support
- Automotive components
- Tooling and wear components
- Armor
- Lightweight, porous ceramics for aerospace systems

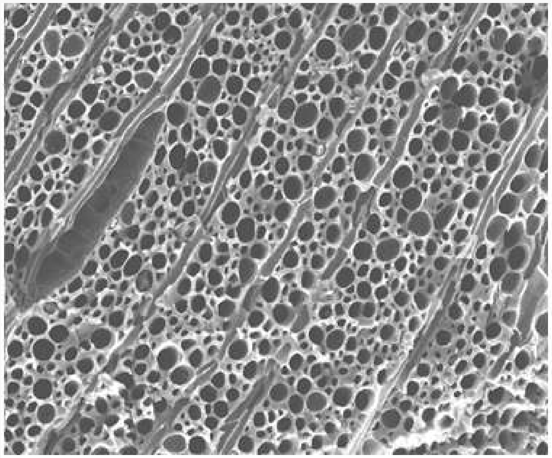


Complex Shaped Ecoceramics Components for a Wide Variety of Applications

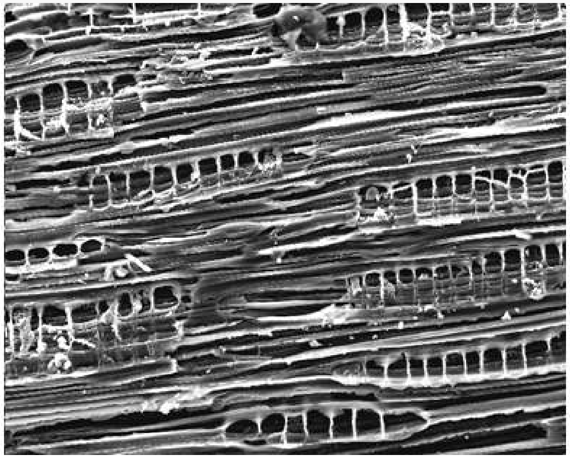




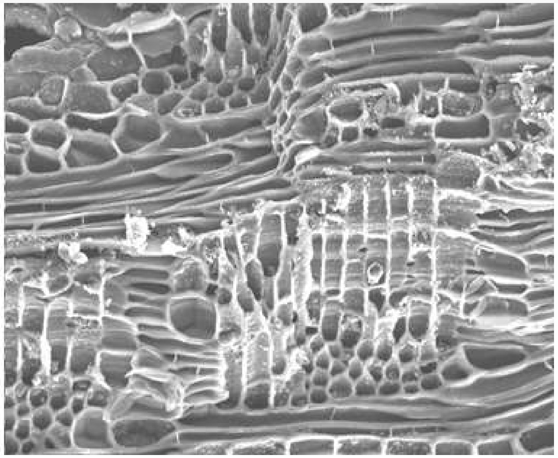
Carbonaceous Preform Microstructure Depends on the Microstructure of Wood



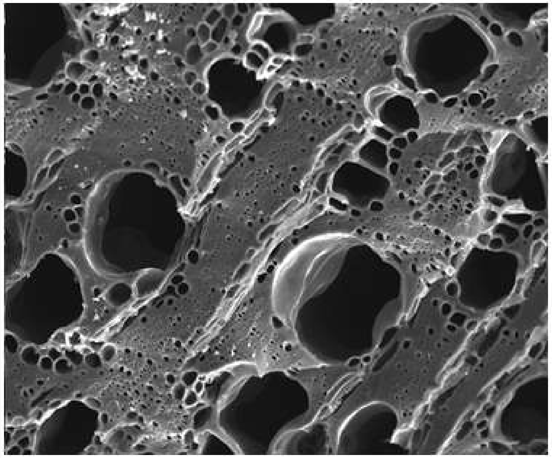
Brazilian Rosewood (300 X)



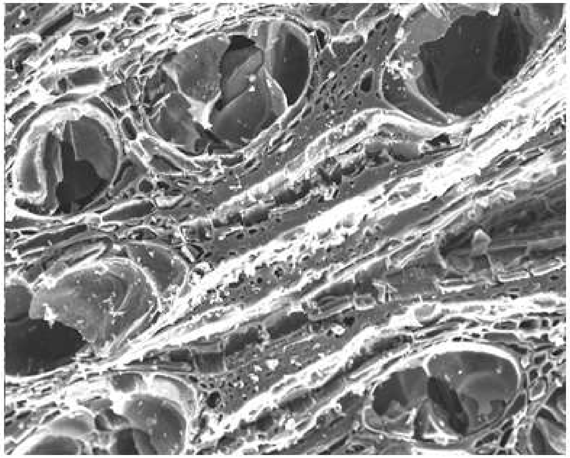
African Zebra (300 X)



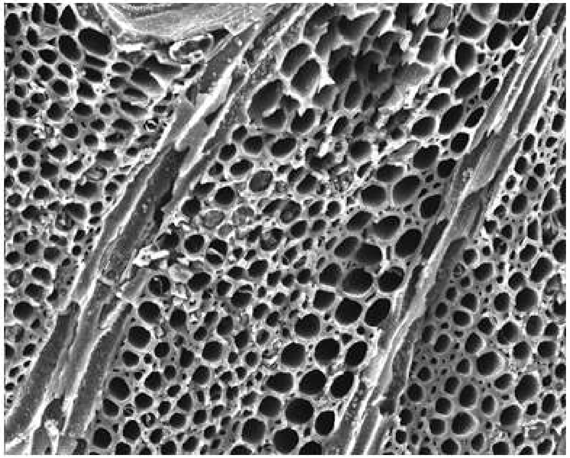
Ceylon Satinwood (300 X)



Pau Lope (200 X)

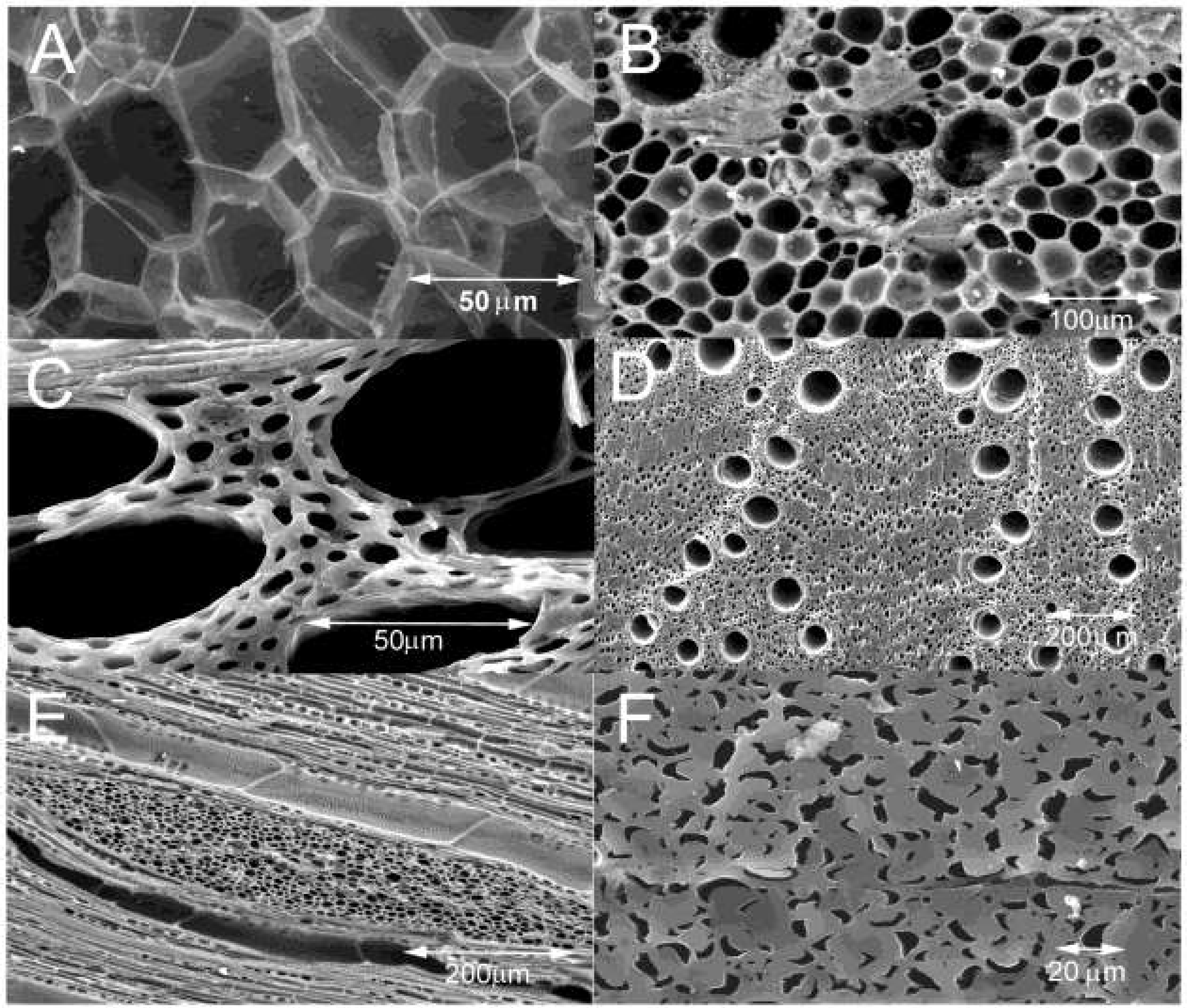


Australian Jarrah (200 X)



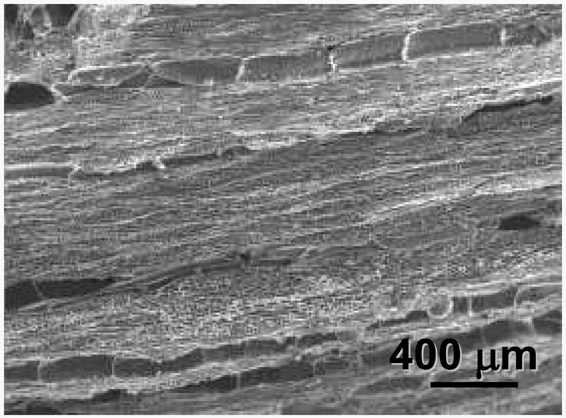
African Bubinga (100 X)

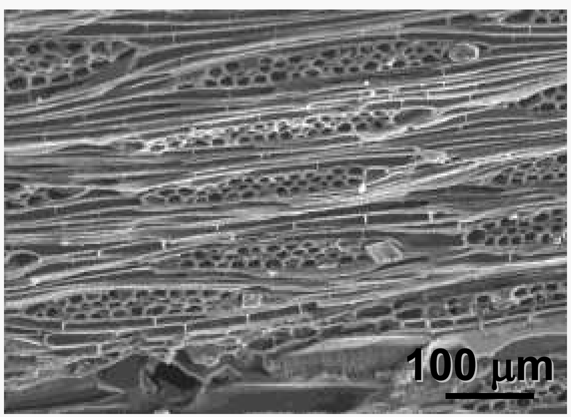
Carbonaceous Preform Microstructure Depends on the Microstructure of Wood



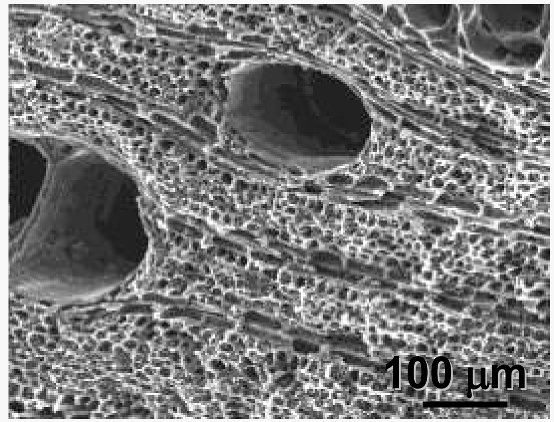
A) cork, B) bamboo, C) beech, D) Spanish oak (axial), E) Spanish oak (longitudinal), and F) red eucalyptus

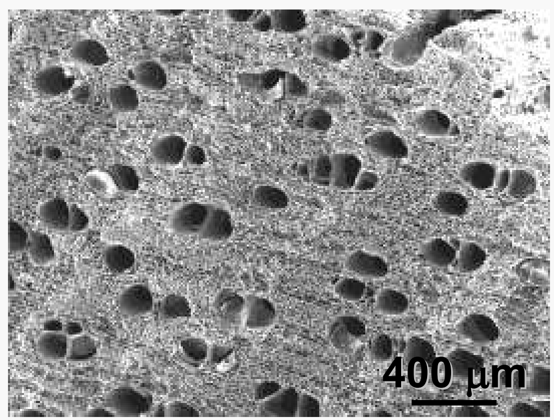
Microstructure of Porous Carbon Preforms and Silicon Carbide from Mahogany



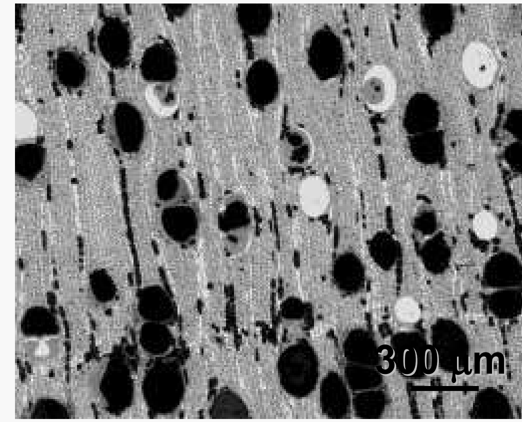


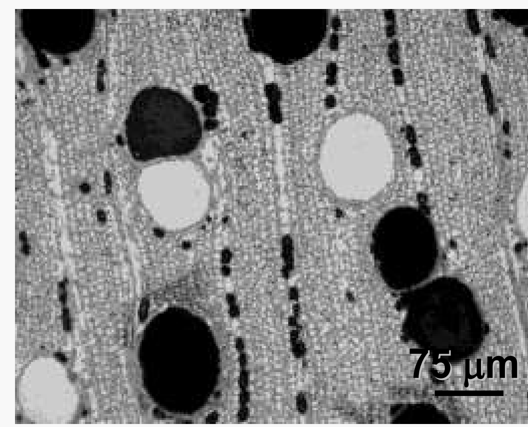
Parallel to Growth Direction





Perpendicular to Growth Direction

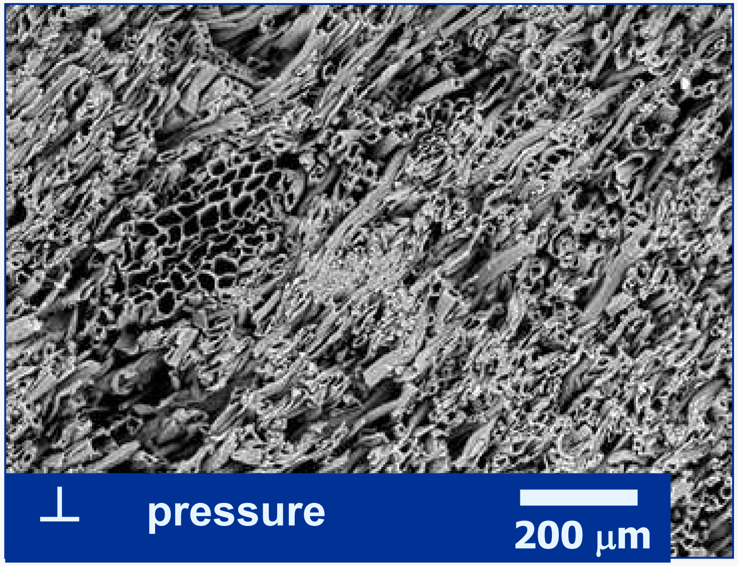


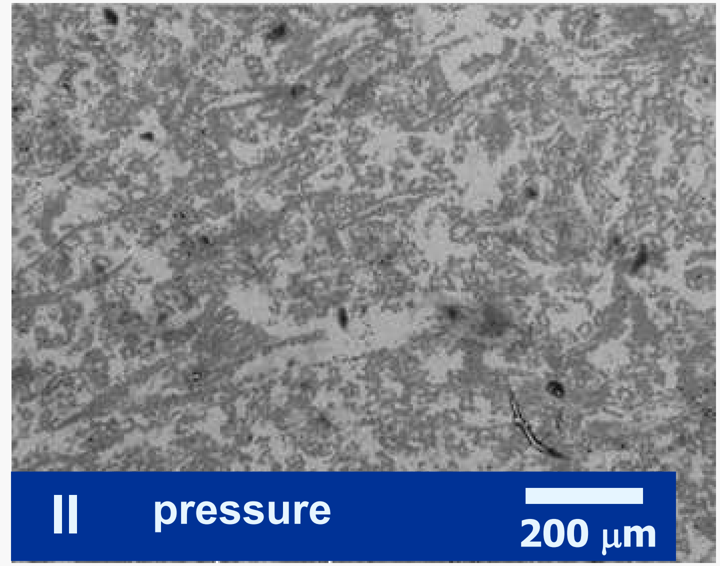


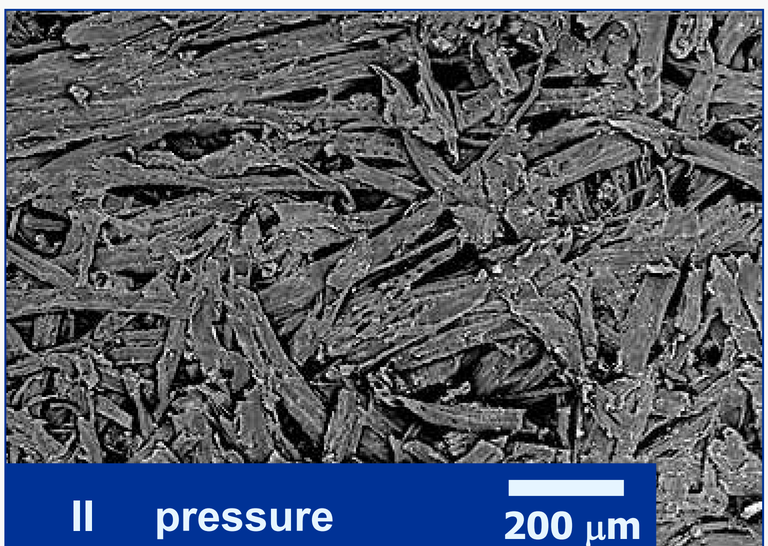
SiC Ceramics: Perpendicular to Growth Direction

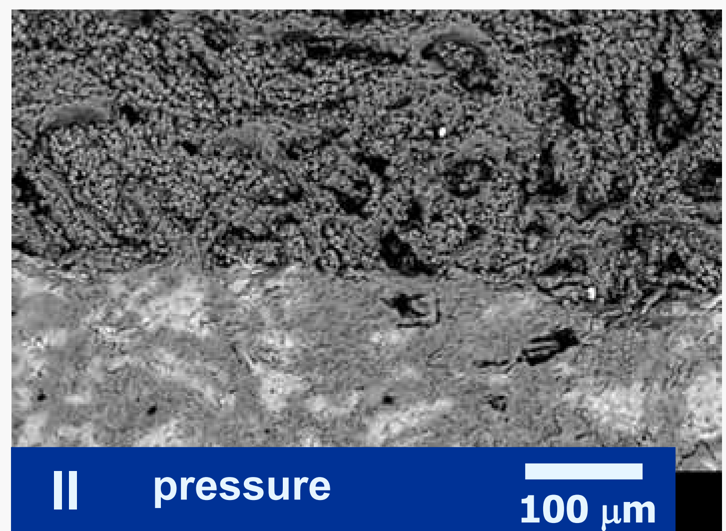
Biomorphic Silicon Carbide Ceramics from Medium Density Fiber Board (MDF)

CARBON





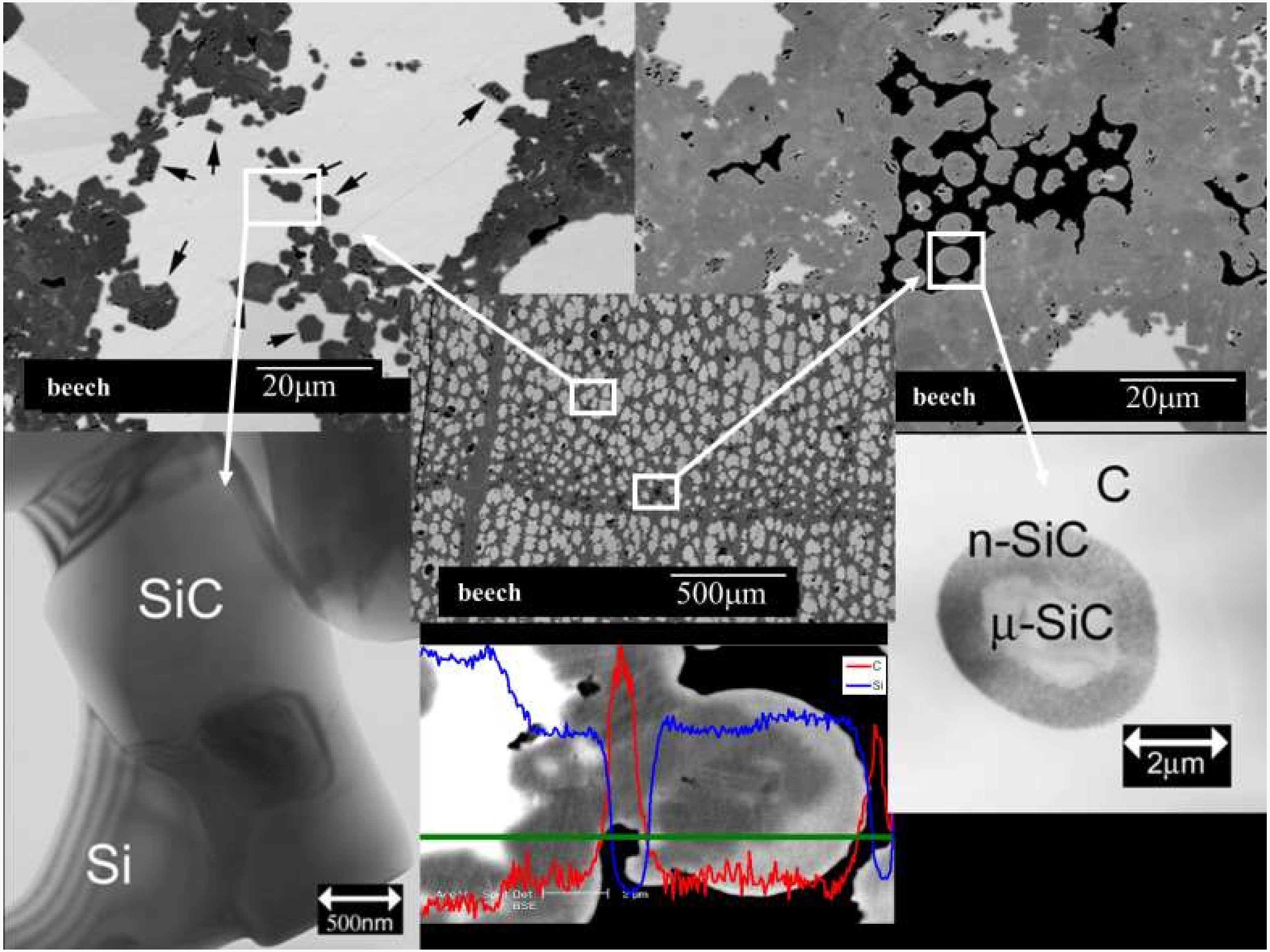




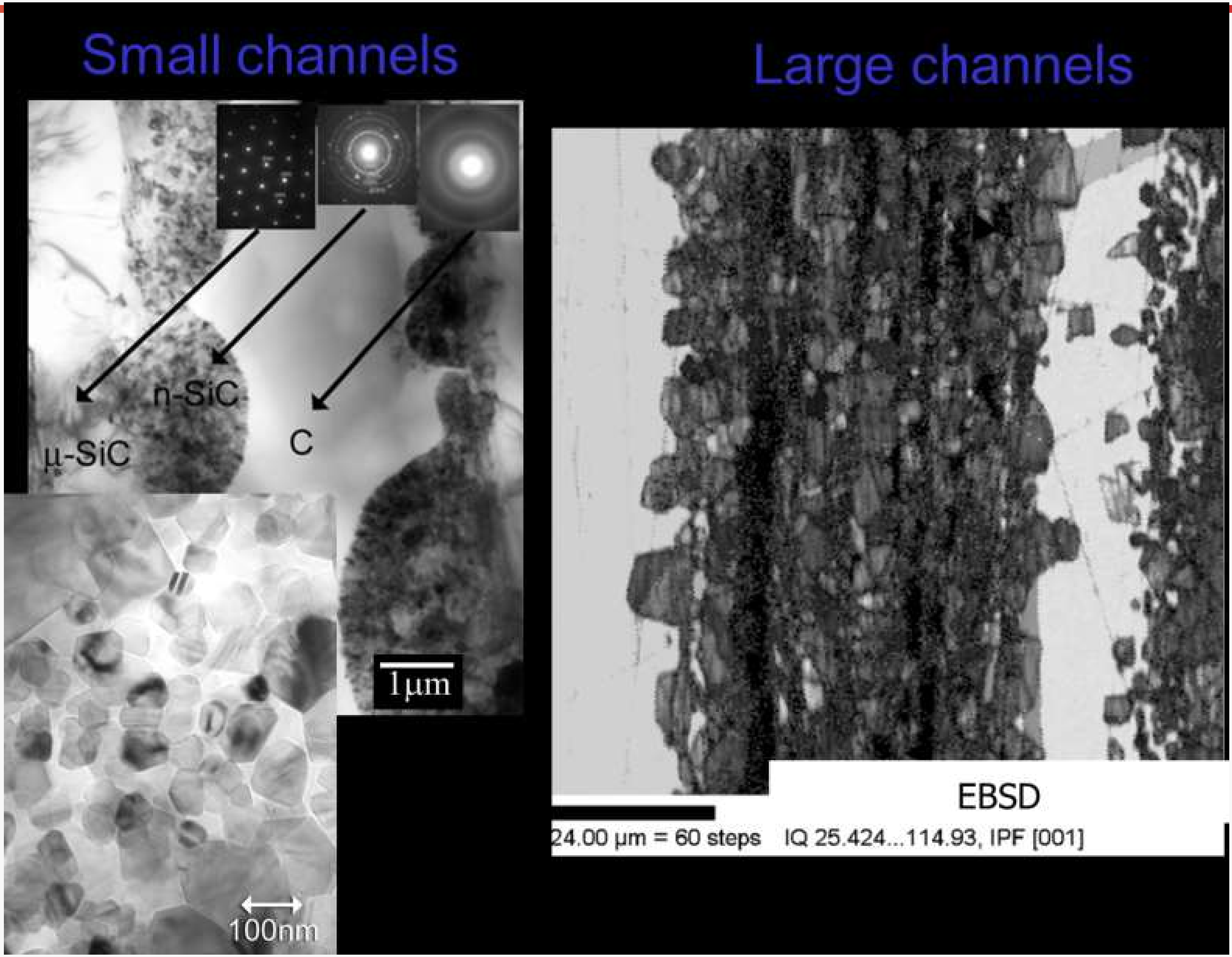
SiC/Si

Julian Martinez-Fernandez, University of Seville, Spain

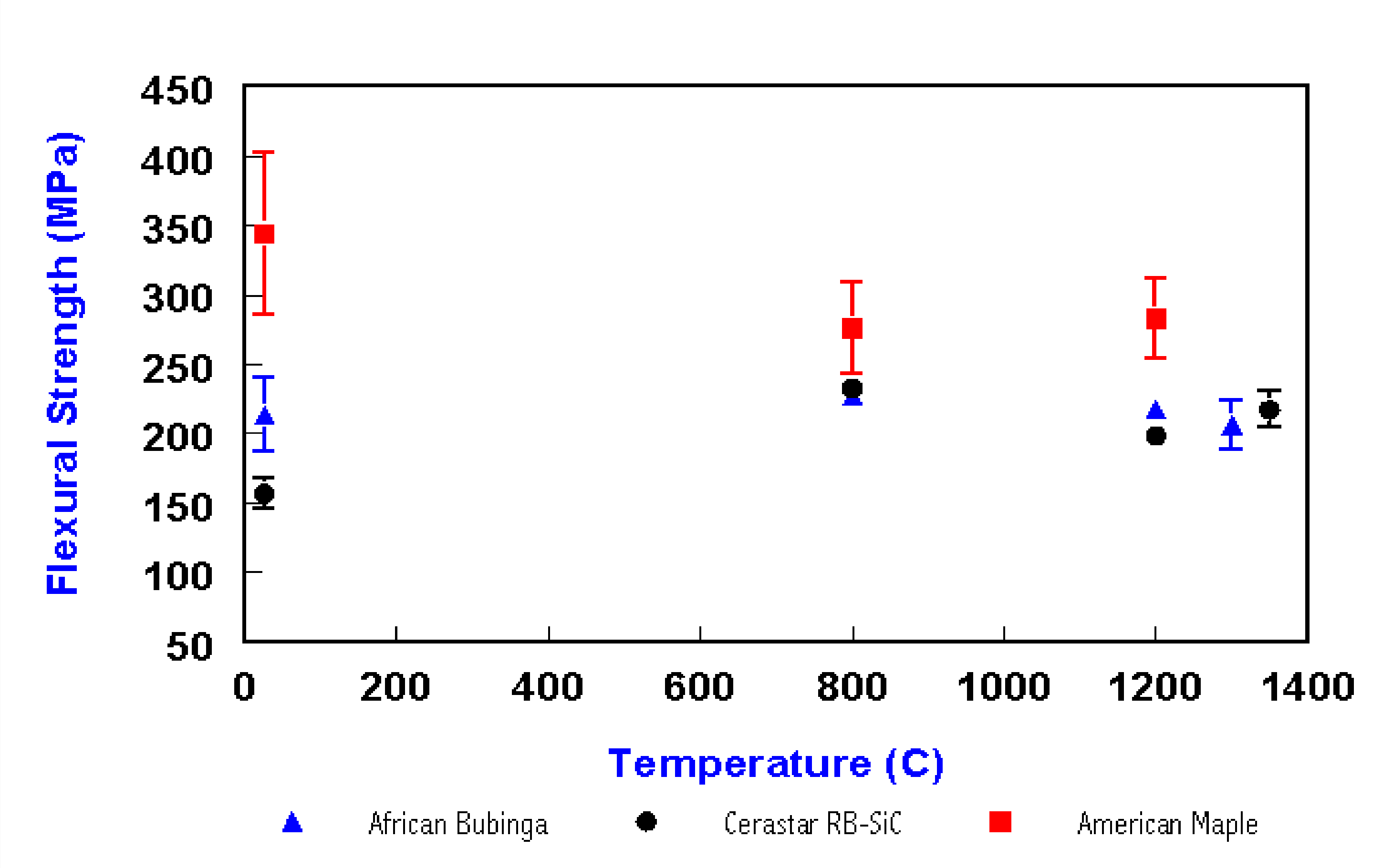
TEM Analysis of Biomorphic Silicon Carbide Microstructures



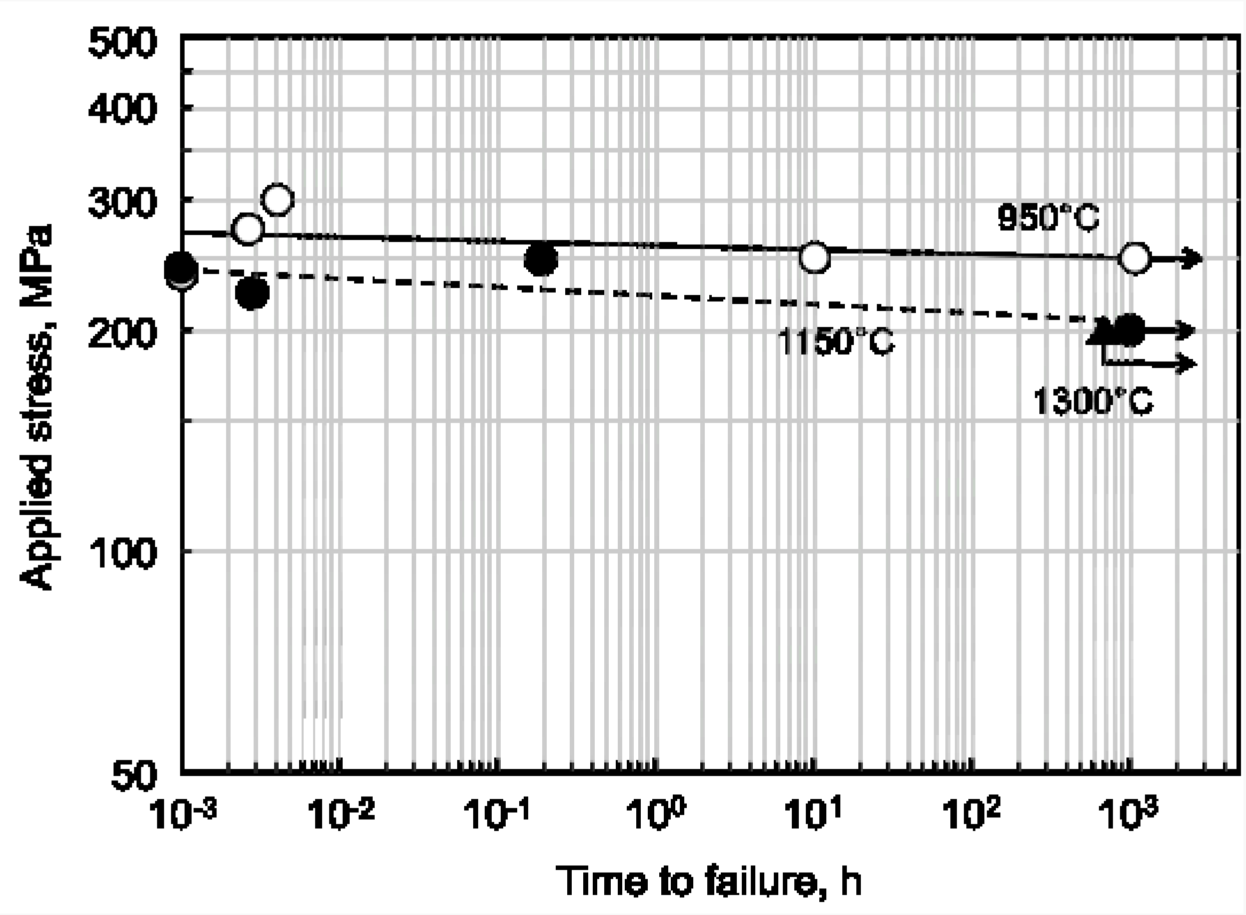
TEM Analysis of Biomorphic Silicon Carbide Microstructures



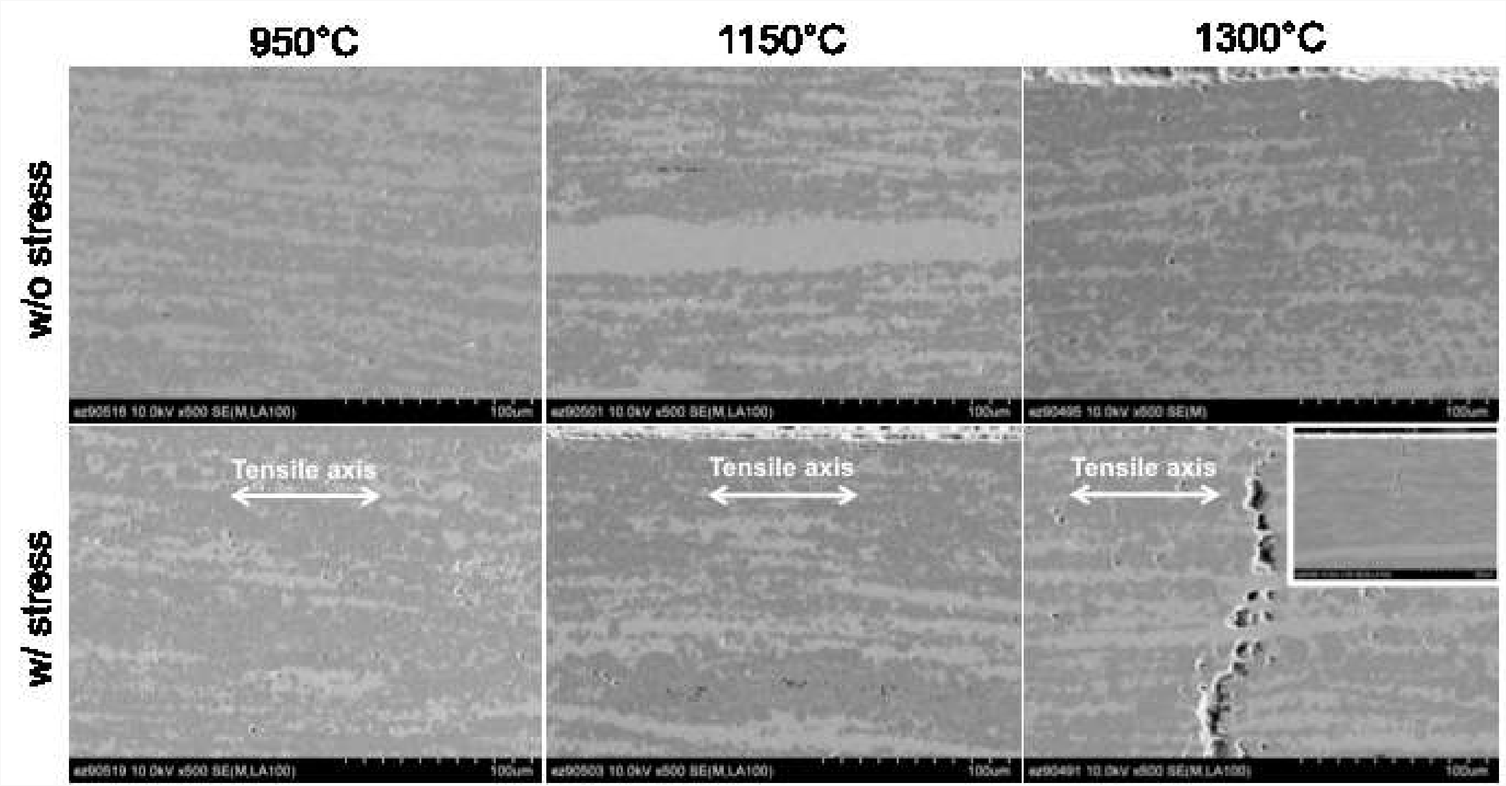
Mechanical Properties of Ecoceramics and Commercial RB-SiC at Different Temperatures



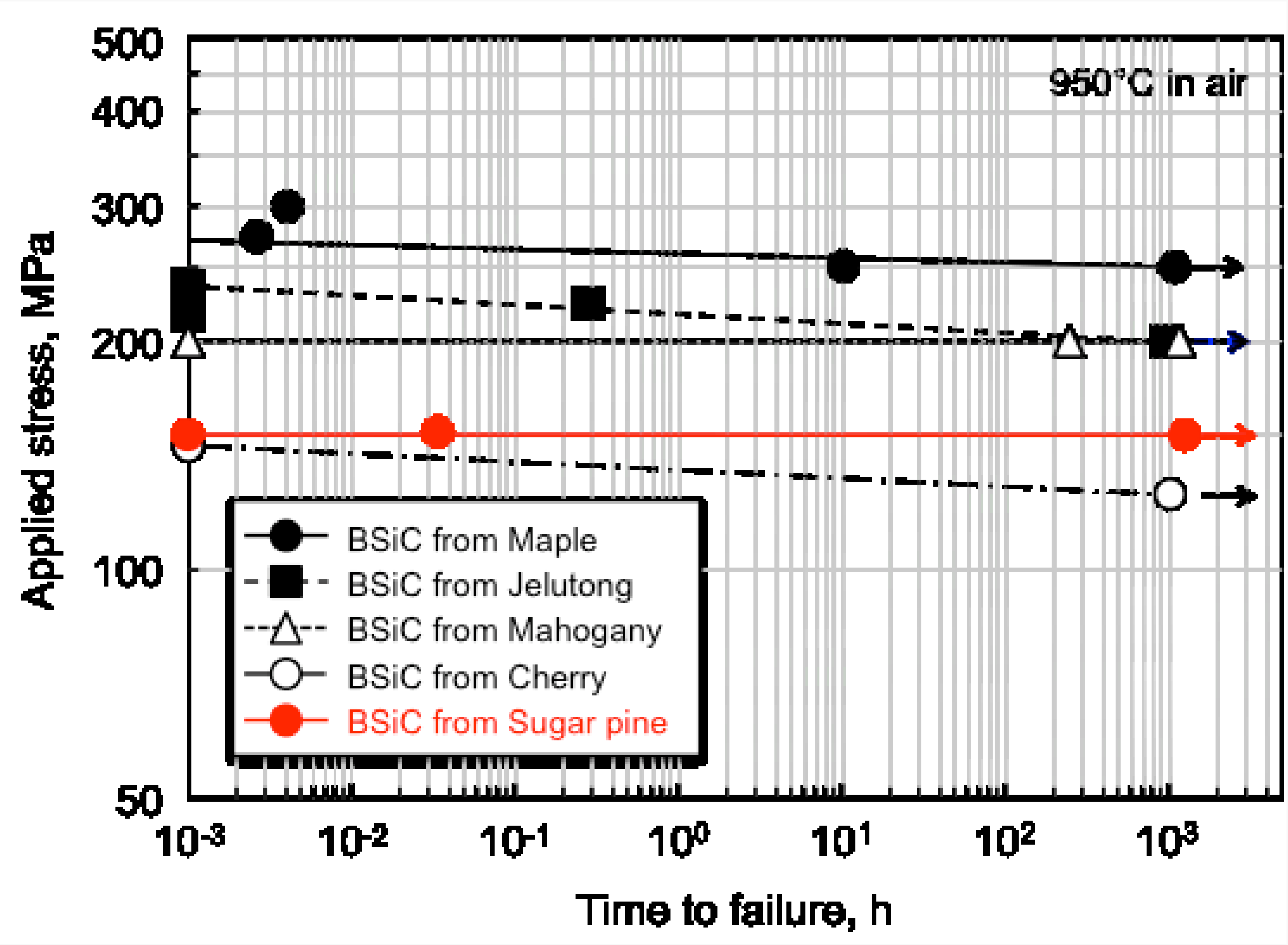
Time-to-Failure Behavior of Maple Derived SiC Ceramics from 950-1300˚C in Air



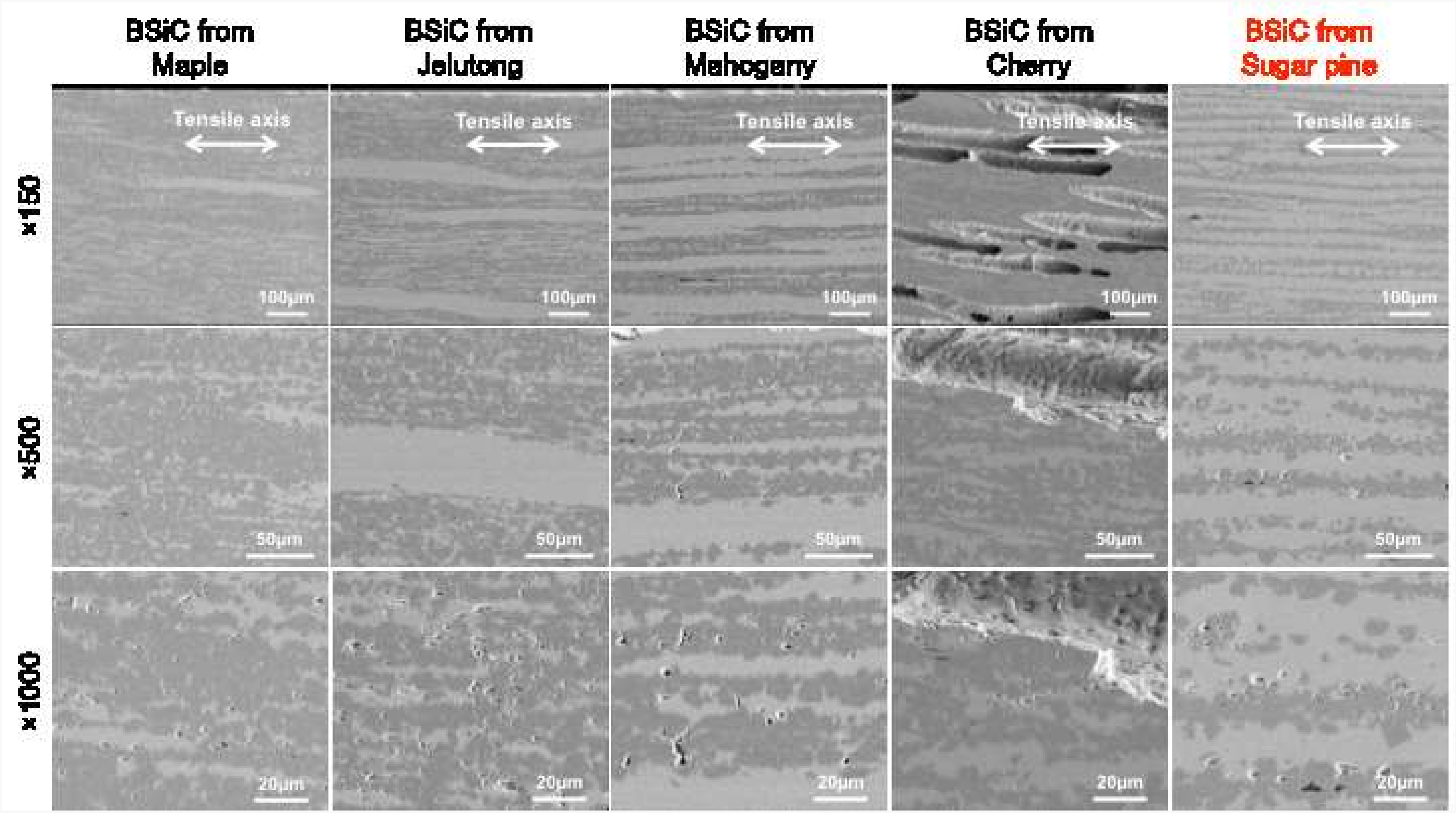
Post Test Evaluation of Maple Derived SiC Ceramics from 950-1300˚C in Air



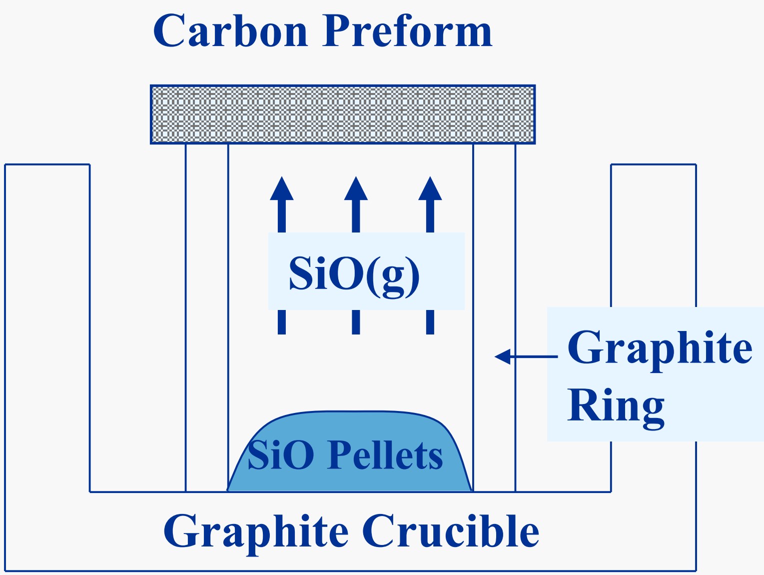
Time-to-Failure Behavior of Various Biomorphic SiC Materials at 950˚C in Air

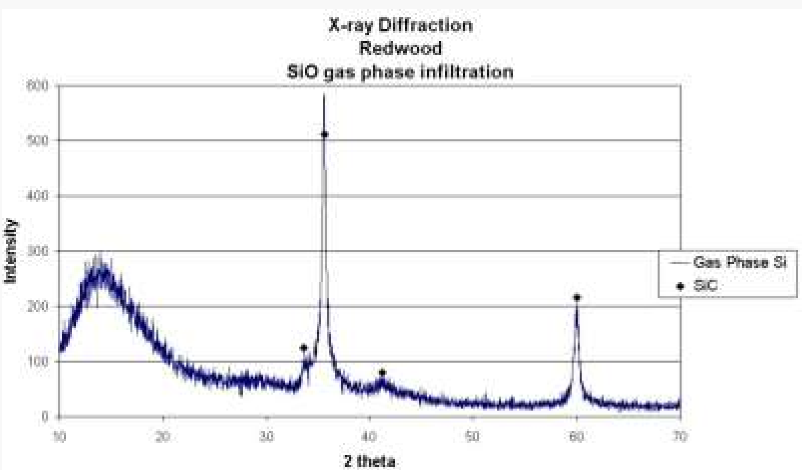


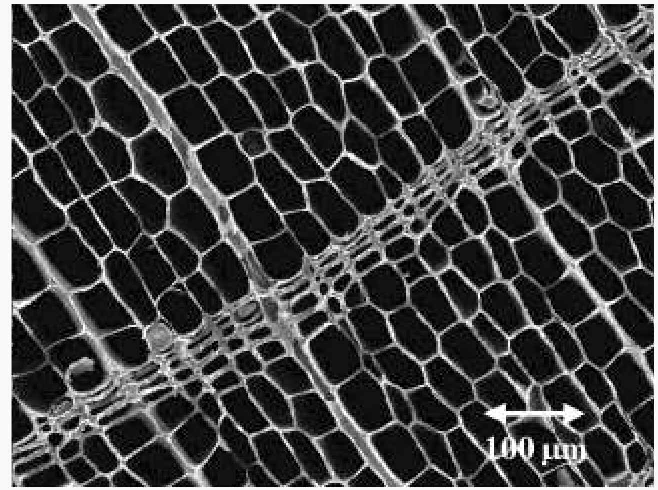
Longitudinal BSE Images of the BioSiC Materials after Testing over 1000h/950˚C/Air

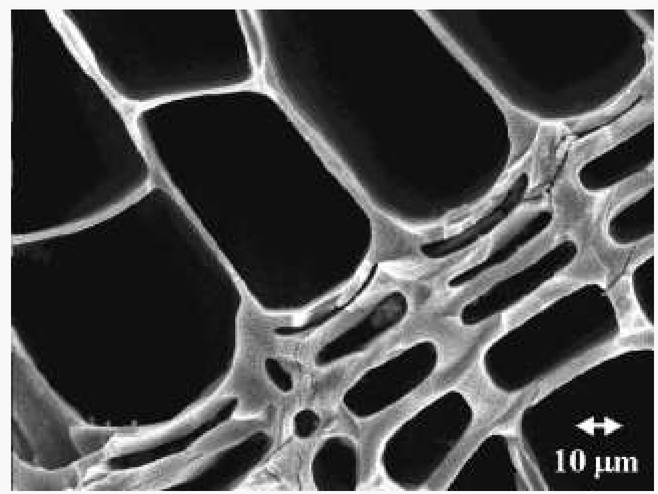


Templates for Growth of Nanotubes and Phase Change Materials (PCMs) for Energy Storage Devices

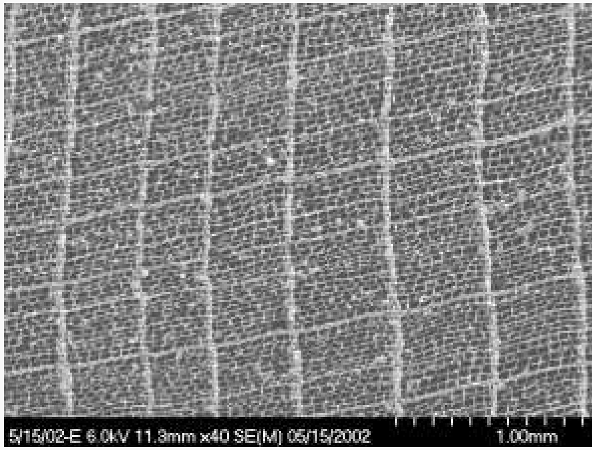


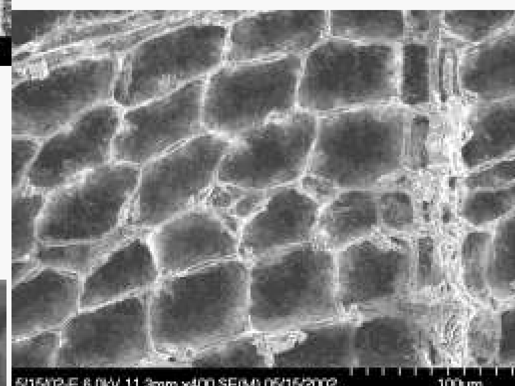


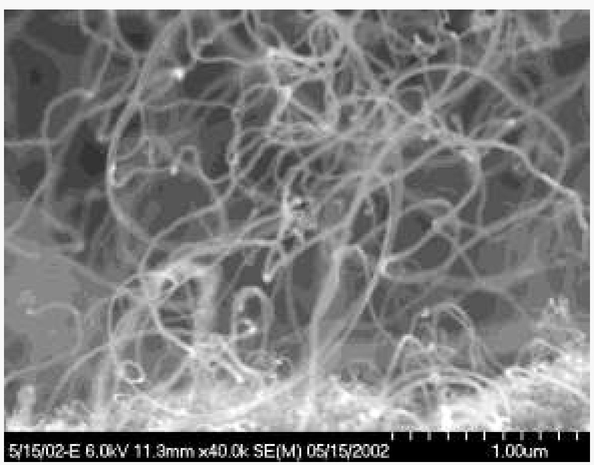


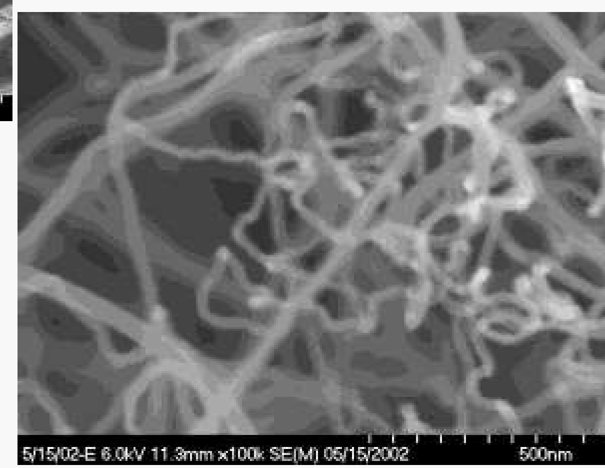


Growth of Carbon Nanotubes in Carbon Derived from Cellulose Templates (Redwood)

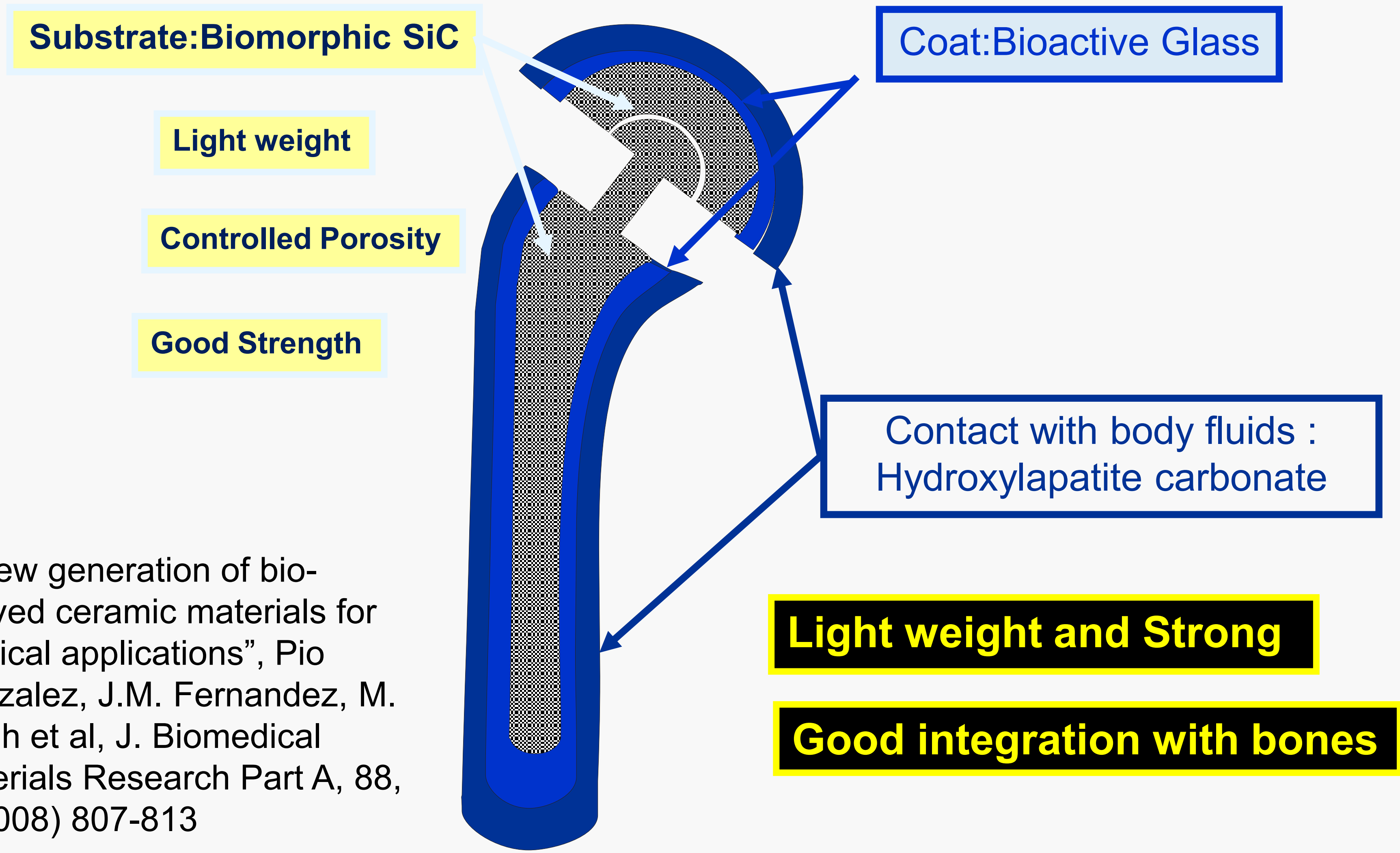








New Approach for Developing Biomaterials for Orthopedic Impalnts

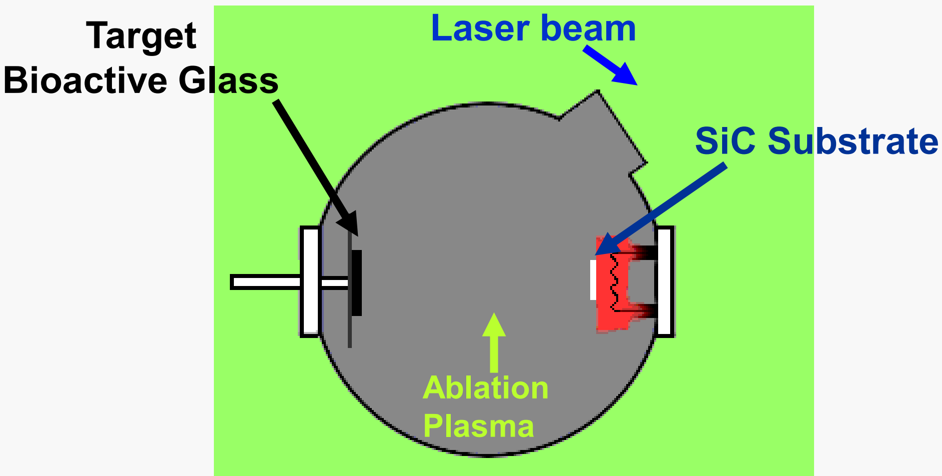


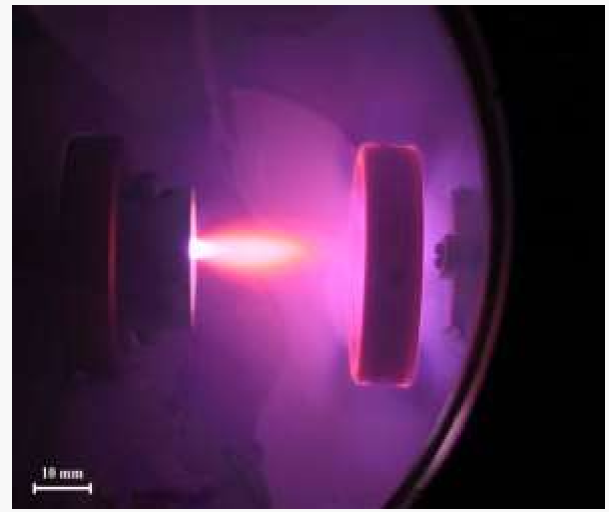
"A new generation of bio-derived ceramic materials for medical applications", Pio Gonzalez, J.M. Fernandez, M. Singh et al, J. Biomedical Materials Research Part A, 88, 3 (2008) 807-813

Fabrication of Coated Specimens

Pulse Laser Deposition (PLD)

Commercial Technique : Plasma Spray





- Low adhesion to substrates

- Deposition of high melting point materials
- Good adhesion between layers
- Stoichiometric composition
- No contamination

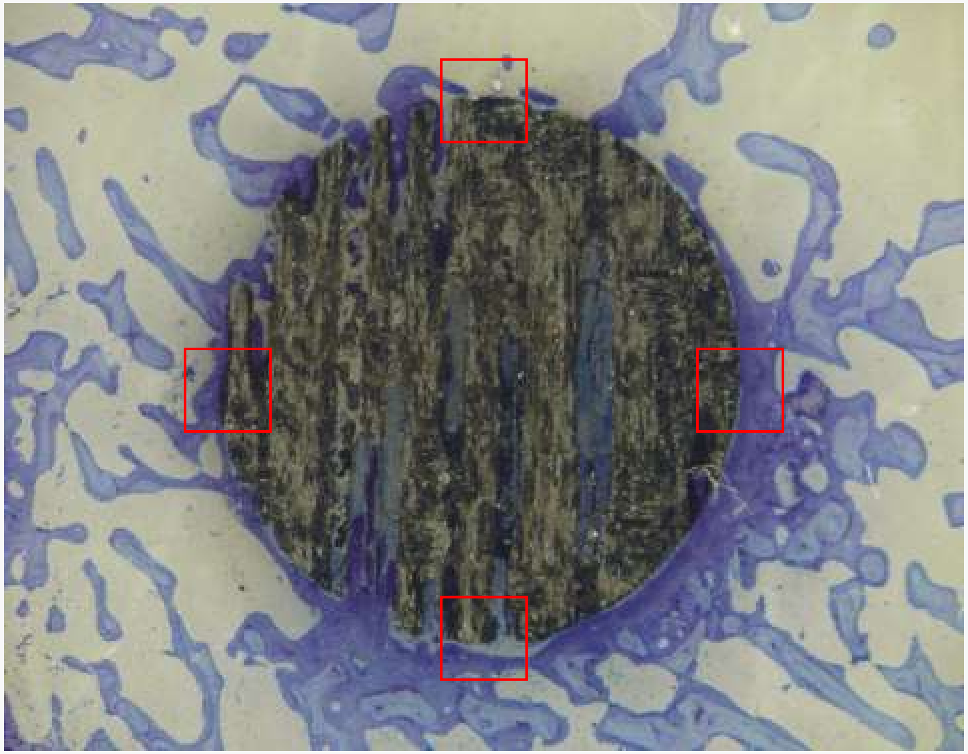
Implant Materials and Evaluation Methods

- **Biomorphic SiC (bioSiC) and Titanium cylinders (4mm diameter,10mm length) were implanted in femur condyle of 15 rabbits.**
- **Twelve weeks later, specimens of 30 µm thick were studied by Optical Microscopy (OM), Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS)**

“Medical Devices Based on Bioinspired Ceramics”, Pio Gonzalez, M. Singh, J.M. Fernandez in “Advances in Biomaterials” B. Basu et al. editor, Wiley (2009) pp 357-409.

PERIPHERICAL OSTEOINTEGRATION

- New bone formation around the implant
- No relevant inflamatory reaction and no fibrous tissue in the bone-implant boundary
- Bone density analysis at four cardinal points (1 mm^2)



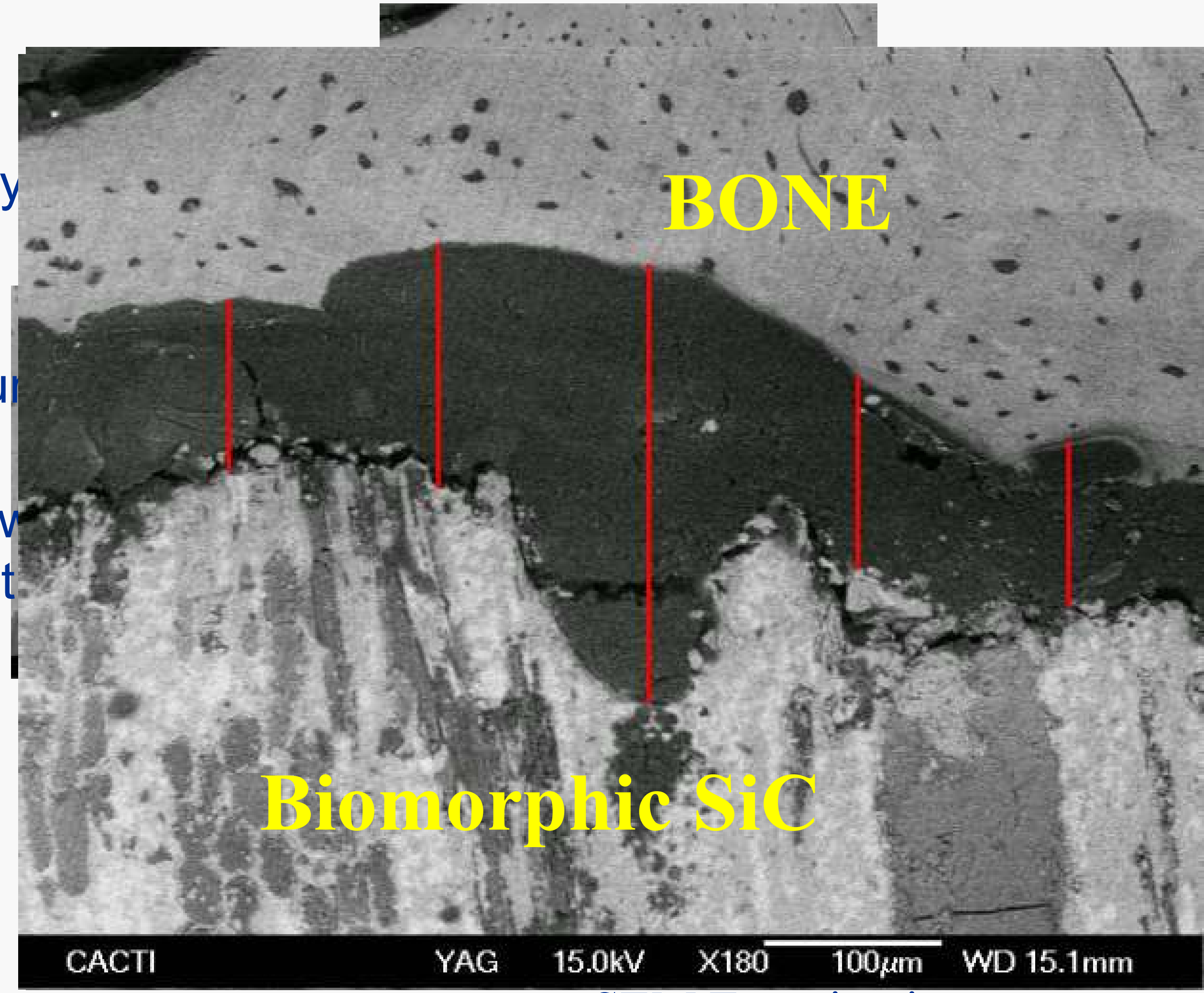
Histological examination

PERIPHERICAL OSTEOINTEGRATION

- Detailed surface analy

- Bone-Implant interface measurement

- The bone grows arour implant.
- Minimal interface betw bone and SiC implant



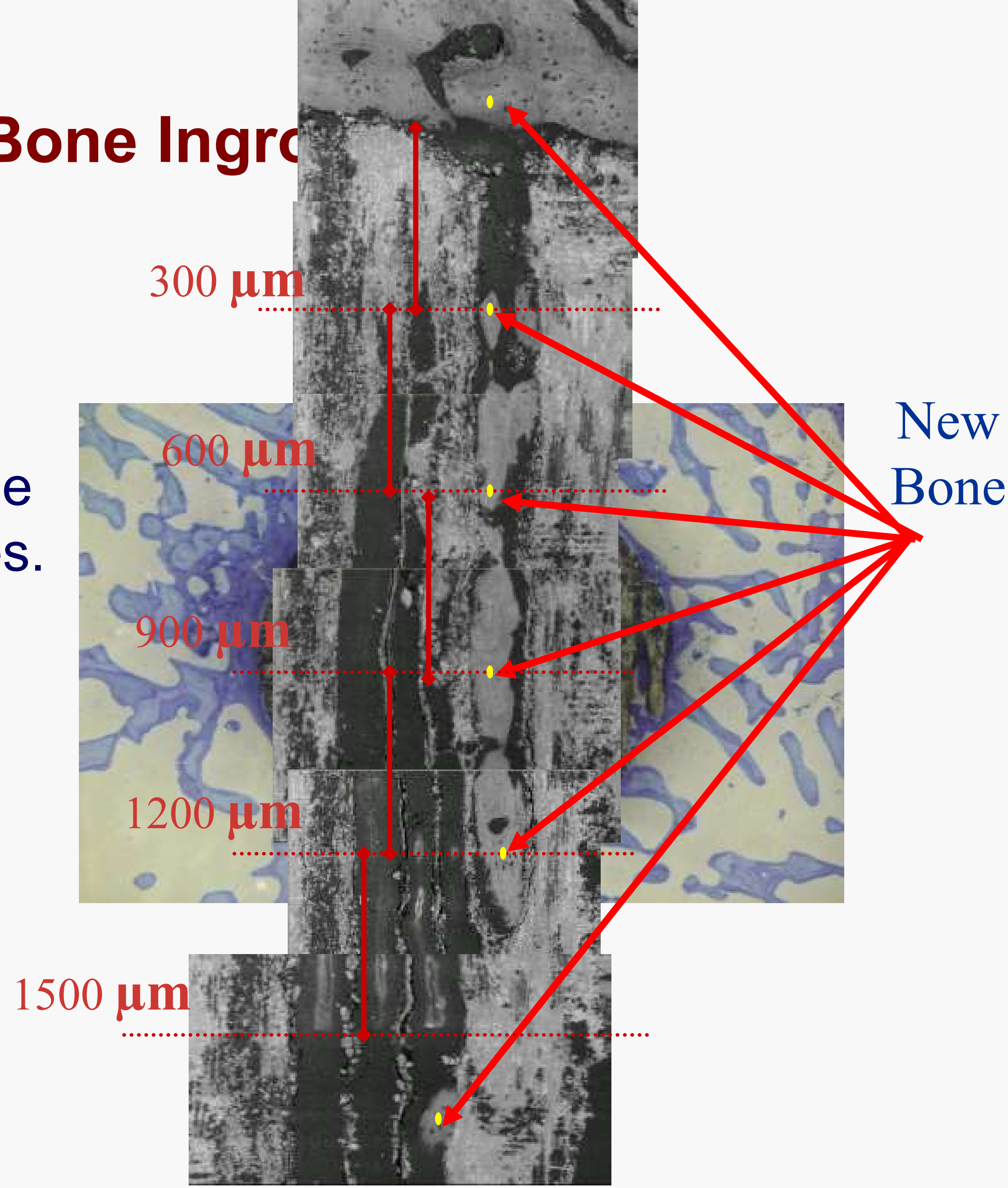
SEM Examination

Bone-Implant Interface Thickness

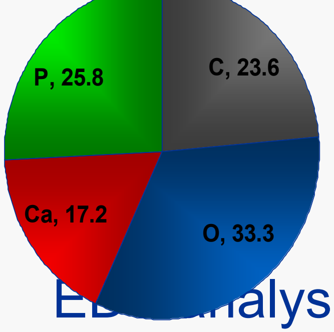
	Bone-implant interface thickness (microns)					
Implant	1	2	3	4	5	**Average**
Pine-SiC	71,4	84,6	60,1	54,4	99,1	**73,9**
Sapeli-SiC	34,3	65,1	78,5	43,8	56,1	**55,6**
Titanium	35,1	11,7	27,0	33,8	50,6	**26,6**

Bone Ingro

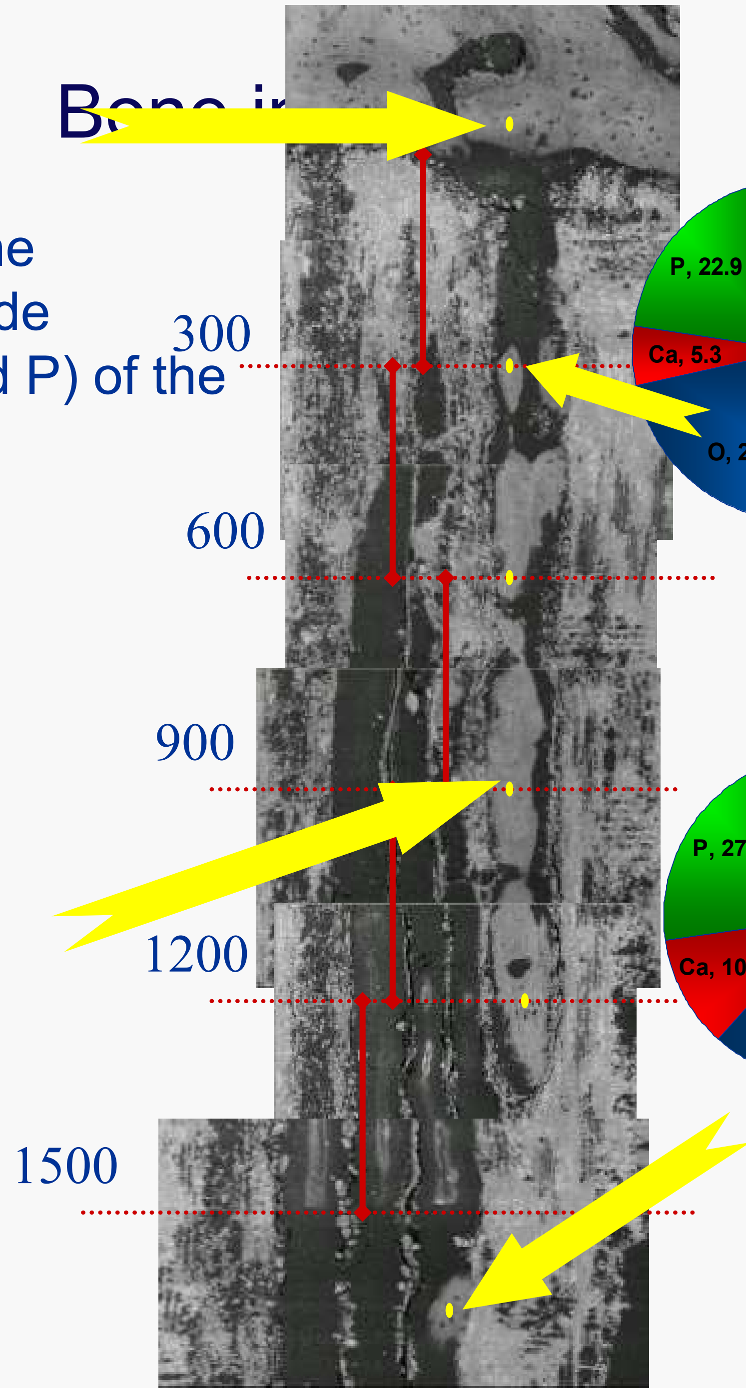
- Limited study (2D)
- SEM shows new bone growing into the pores.

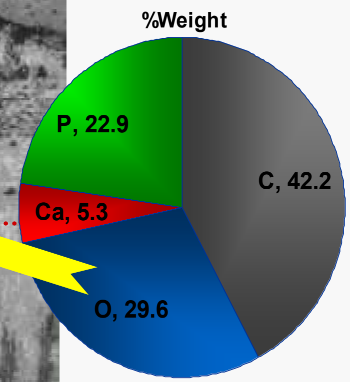


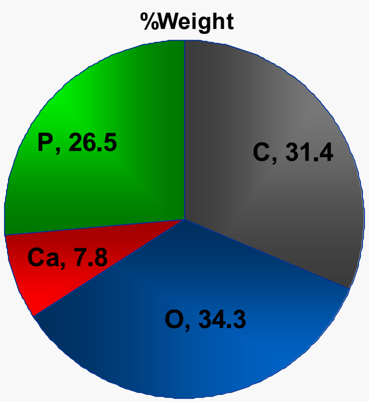
Bone in

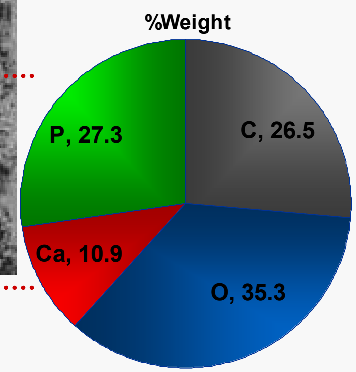


- ED analysis of the mineralization grade (amount of Ca and P) of the ingrowth bone.









Summary and Conclusions

- Biological systems in nature can provide valuable information and guidance in design and manufacturing of new classes of materials.
- In the fabrication of biomorphic ceramics from cellulose templates, the original biostructure is retained throughout processing, which allows control of properties of the end products.

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